A Preliminary Study to Quantify Vertical Wind Velocity from Doppler Spectra Collected by Vertically Pointing K-Band Radars

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ISAC

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1. MOTIVATION AND GOLAS OF THE WORK

- ❑ The relationship between raindrop size and fall velocity is at the base of the particle size distribution (PSD) retrievals by vertically pointing Doppler radars.
- ❑ Drop fall velocity (v_f) is usually assumed to follow its behavior in still air, but the observed velocities (v_c) include the vertical wind component (v_w) that add to the drop fall velocities in still air thus introducing a bias in PSD retrieval.
- ❑ For the above mentioned reason the inversion of the radar Doppler spectrum to a PSD is not is not always straightforward
- ❑ Turbulence and vertical wind strength can modify the radar Doppler spectrum thus modifying it with respect to still air conditions which is the main assumption at the base of the PSD inversion strategy.
- ❑ Adirosi et al. (2016) introduced a mean to detect (v_w) effect at low level using a reference disdrometer.

❯❯❯ GOAL 1: Develop and test strategies to ***extract vertical wind information from complete MRR profiles***

❯❯❯ GOAL 2: ***Evaluate the impact of environmental vertical wind velocity on MRR profiles of rain PSD***

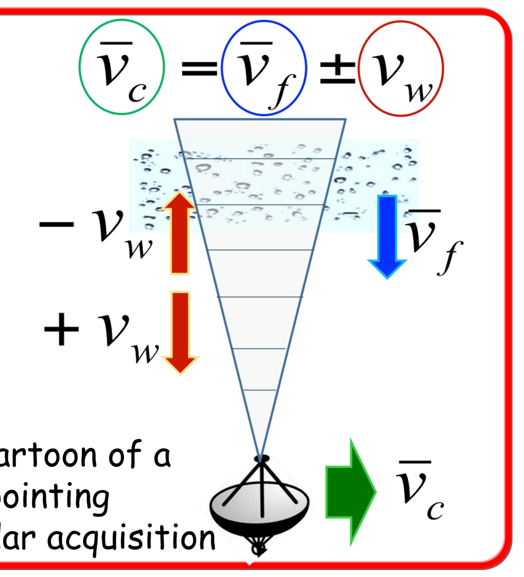


Figure 1: Cartoon of a vertically pointing Doppler radar acquisition

2. AVAILABLE MEASUREMENTS: MC3E IOP 2011

- ❑ **The Mid-latitude Continental Convective Clouds Experiment (MC3E** *M. P. Jensen et al., BAMS 2016*)
  - ➢ MC3E is a field campaign aimed at acquiring a more complete understanding of the physical processes driving the life cycle of mid-latitude convective clouds.
  - ➢ MC3E represents a collaborative effort between the NASA Global Precipitation Mission (GPM) ground validation and the Department of Energy (DOE)
  - ➢ Performed during April-June 2011 in Central Oklahoma (USA)
- ❑ **NOAA radar systems (<u>used in this study</u>):**
  - ◆ 24 GHz (K) MRR profiler (*Petersen et al. 2012*)
    - ○ Profiles of raw spectral reflectivity
    - ○ Sampling time 10 sec (1-min averaged for comparisons), range res. 35 m from 35m to 1085 m agl.
  - ◆ 2.8 GHz (S) profiler combined with 449 MHz (UHF) wind profiler (*Williams, 2012*)
    - ○ Profiles spectral average velocity of vertical wind and its spectral width
    - ○ Sampling time 1-min, range resolution 62.4 m from 221 m to 3905 m agl.

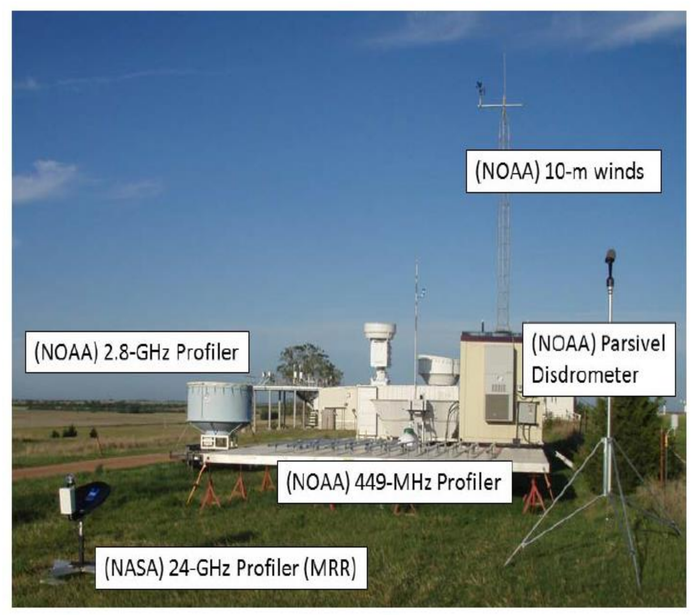


Figure 2: Instruments deployed in Mid-latitude Continental Convective Cloud Experiment (MC3E) 22April – 6 June 2011

❯❯❯ Total number of matched samples (among MRR, UHF/S): 23100: Total number of matched profiles: 2100; Total number of rainy samples among those matched: 5148

3. MRR PROCESSING

- ❑ MRR data have processed from scratch from raw acquisitions.
- ❑ Steps followed:
  - Noise suppression (*Maahn and Kollias, AMT, 2012*) ← RAW
  - Doppler Unfolding (*Tridon et al, GRL, 2011, Adirosi et al. AR 2016*)
  - Attenuation correction (*Peters et al., JTECH 2010*) → processed
  - Spectral 1-min averages
  - Moments calculations (D_0, LWC, R, Z)

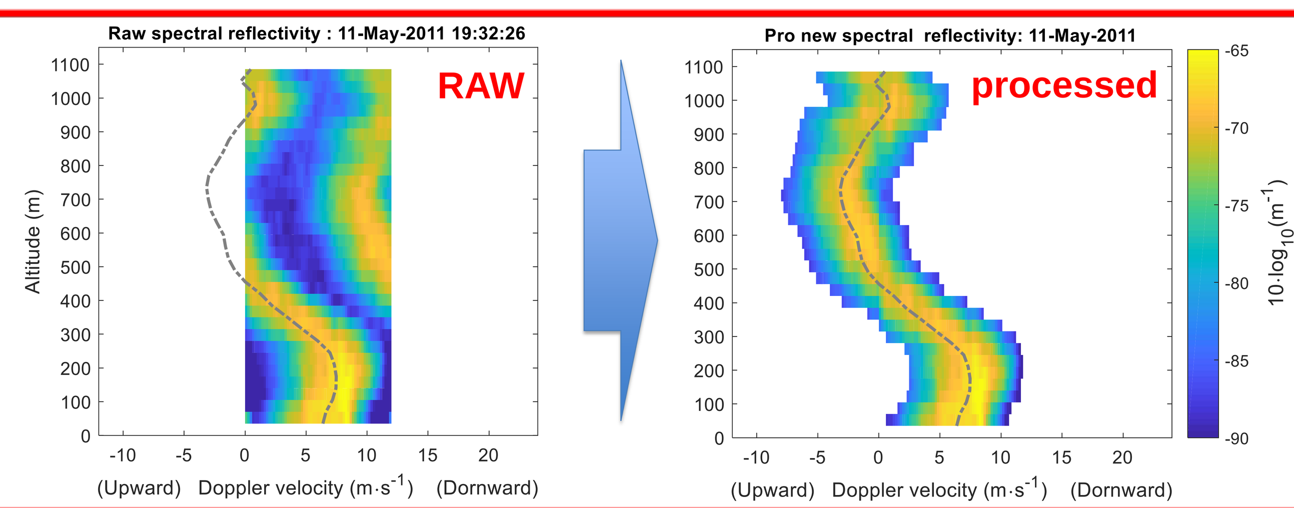


Figure 3: Example of RAW (left) and processed (right) profiles of MRR Doppler spectra.

4. MRR AND WIND PROFILER

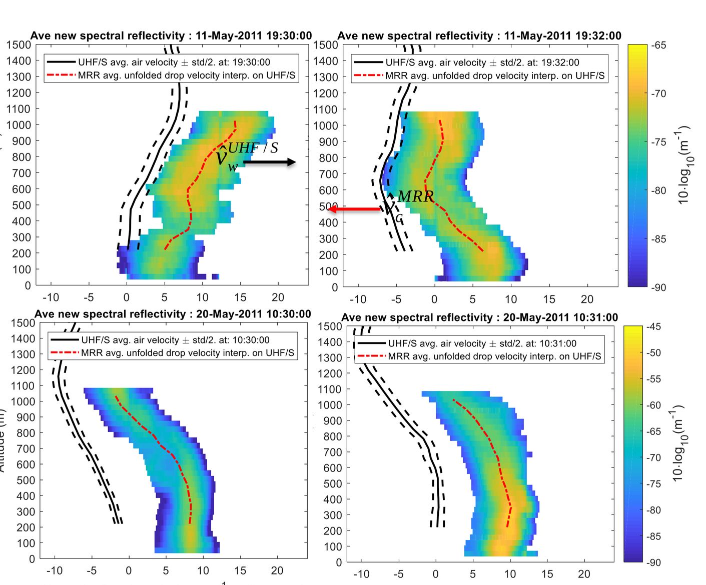
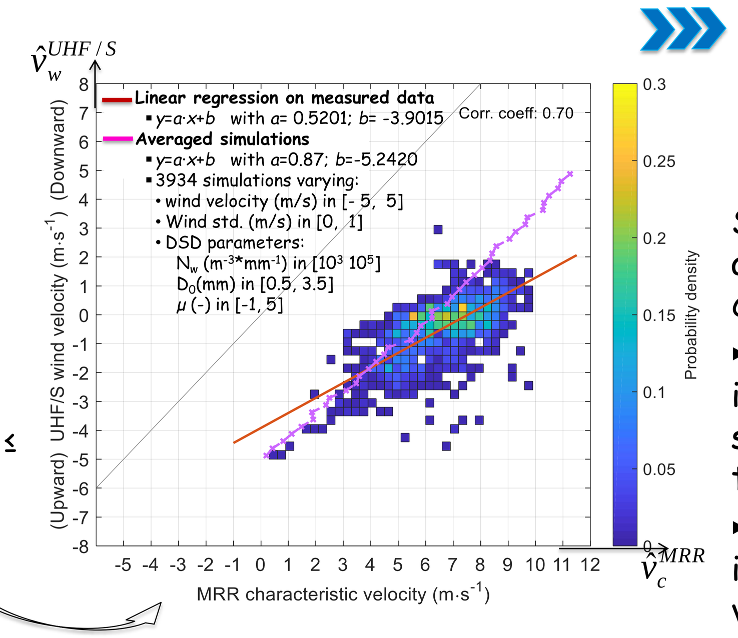


Figure 4: Vertical profiles of MRR Doppler spectra from MRR. Black and red curves are the vertical wind profiles from UHF/S band wind profiler (Williams JTECH 2016) combined product ($v_w^{UHF/S}$) and the characteristic vertical velocity from MRR (v_c^{MRR}), respectively.

Figure 5: Characteristic average vertical velocity from MRR (v_c^{MRR}) vs. vertical wind velocity from UHF/S wind profiler ($v_w^{UHF/S}$), After filtering MRR data having MRR Spectral width ≤ 1.28 m⁻¹ or samples within profiles with a Liquid water path ≤ 110 g·m⁻², the total number of samples displayed results 1086 out of 5148.



❯❯❯ A 0.7 correlation btw. MRR characteristic velocity "v_c" and wind profiler velocity "v_w" evidences a good chance to extract vertical wind information from MRR.

Simulations and measurements don't agree in terms of slope (red and purple curves)., suggesting that:

- ▸ The effect of "v_w" could differently impact the spectral component of MRR spectra and then can alter "v_c" in a way that is not strictly linear.
- ▸ The model of drop's terminal velocity in stagnant air used couldn't be strictly valid anymore in turbulent situations.

5. VERTICAL WIND ESTIMATION FROM MRR

❑ **Method 1:**

- From **figure 5** apply the linear regression trained on measured data of $v_w^{UHF/S}$ and v_c^{MRR}

$$\hat{v}_w(h) = a \cdot \hat{v}_c^{MRR}(h) + b \qquad \text{with } a=0.52;\ b=-3.9$$

❑ **Method 2:**

- From **figure 6** assume particle's fall velocity constant along the vertical

$$\hat{v}_w(h) = \hat{v}_c^{MRR}(h) - \hat{v}_f(h) \qquad \text{assuming} \quad \hat{v}_f(h) = Const. \boxed{= \hat{v}_c^{MRR}(h_m)}$$

❑ **Method 3:**

- Same as Method 2 but particle's fall velocity comes from model simulations (**figure 7**) inverting the equivalent reflectivity factor

$$\hat{v}_w(h) = \hat{v}_c^{MRR}(h) - \hat{v}_f(h) \qquad \text{assuming} \quad \hat{v}_f(h) = c \cdot [Z(h)]^d + e$$

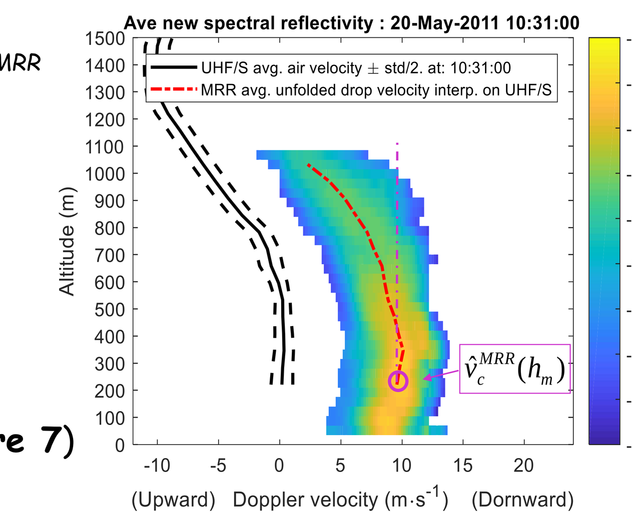


Figure 6: Example of MRR and UHF/S profiles to explain estimation method 2.

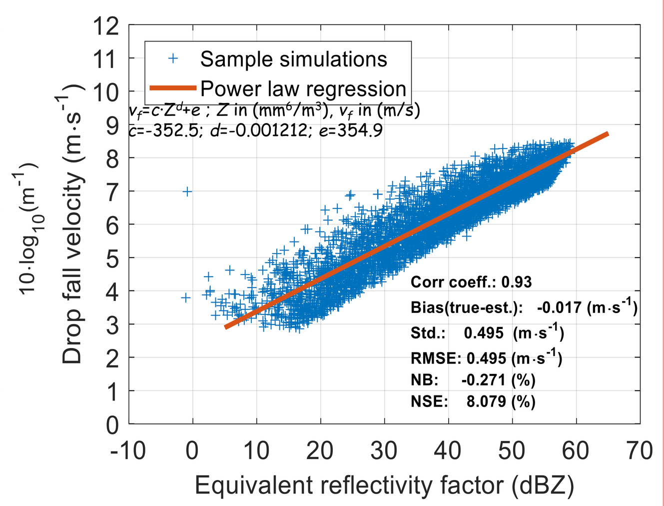


Figure 7: Simulations of equivalent reflectivity factor vs. drop fall terminal velocity.

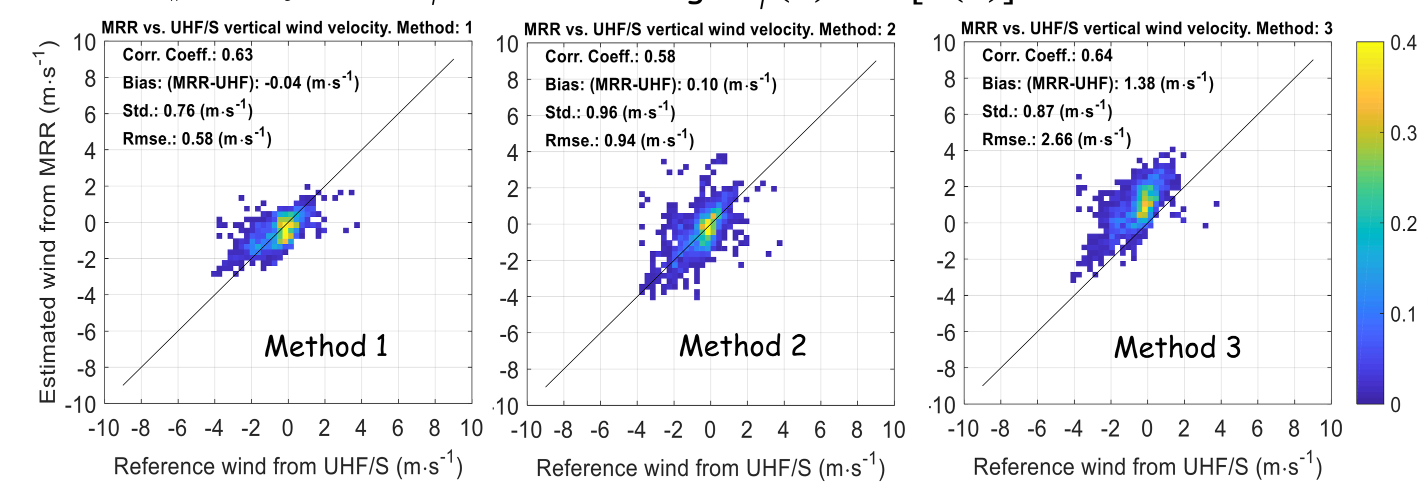


Figure 8: scatterplot of estimated vs. reference vertical wind.

	Skill scores for vertical wind orientation estimation					
	PC (%) [0, 100]	FD (%) [0, 100]	POD (%) [0, 100]	FAR (%) [0, 100]	CSI [0, 1]	ETS [-1/3, 1]
Method 1	72.09	16.42	47.62	42.36	0.35	0.20
Method 2	73.52	16.42	68.05	42.76	0.45	0.27
Method 3	48.60	74.54	98.32	61.96	0.38	0.09

Table 1: error score indexes of the estimation of wind orientation

❯❯❯ Method 2 is particularly promising because it is extremely easy and self-consistent and it does not require to fix a-priori coefficients.

❯❯❯ In addition, Method 2 performs best in terms of skill score indexes of wind orientation (**Table 1**)

6. IMPACT OF VERTICAL WIND VELOCITY ON DROP SIZE DISTRIBUTION RETRIEVALS

- ❑ Measured-MRR spectra are compensated (*C*) for vertical wind shift using coincident UHF/S band retrievals.
- ❑ A new estimate of compensated Drop Size Distribution (DSD) and its moments is performed and it is compared with the uncorrected (*U*) ones.

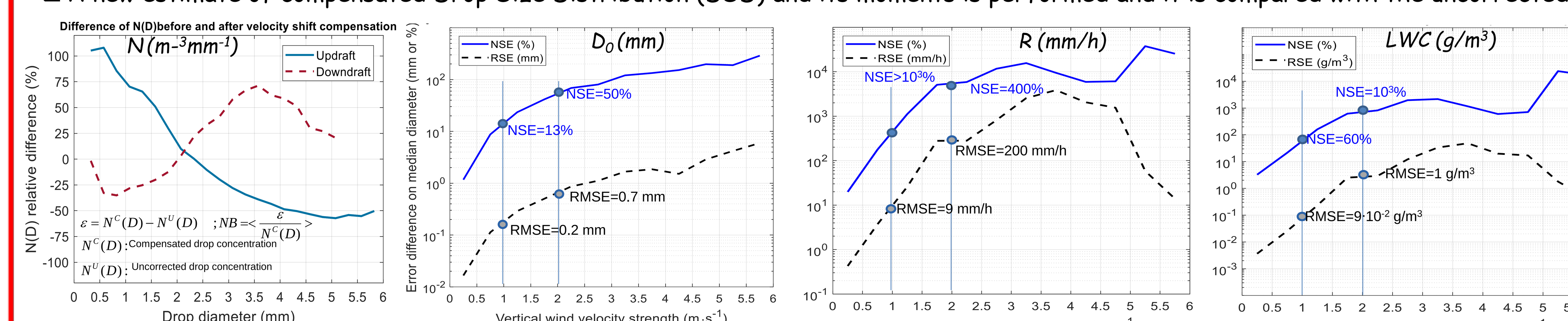


Figure 9 : Error score of PSD, D_0, R and LWC as a function of vertical wind from S/UHF product.

❯❯❯ Differences in N^U & N^C vary with D and depends by vertical wind orientation. Updraft→ If not corrected N^U is underestimated for D<2mm & overestimated for D>2 mm and viceversa for downdtraft.

❯❯❯ A small vertical wind as 1 m/s produces a bias in D_0 of the order of 10%

❯❯❯ A small vertical wind as low as 0.5 m/s is enough to bias the rain rate of the order of 60%

7. CONCLUSIONS

Comparison between vertical wind velocity and average characteristic velocity during convection from UHF/S wind profiler and K-band MRR, respectively, suggest

- ○ *A liner correlation of 0.7 between the two sources in case of severe convection. and a quite interesting disagreement between model simulations and measurements in terms of characteristic drop fall velocity which may indicate some errors introduced assuming stagnant air hypothesis of drop fall velocity during turbulent events.*

A promising easy and self-consistent method for vertical winds retrieval from MRR has been developed and preliminarily tested:

- ○ *Detection capability in terms of vertical wind orientation of the order of 75% (proportion correct) and 20% (false detection)*
- ○ *Retrieval errors of wind strength as RMSE =0.94 m/s; BIAS=0.1 m/s and STD=0.96 m/s, Cc=0.6*

Measurement-driven impact of vertical wind on Rain Drop Size Distribution related quantities shows:

- ○ *A variation between Uncorrected and Corrected PSD is of the order of [-50, 100]% which is variable through the drop diameters and l wind strength and direction.*
- ○ *A precautionary threshold that allow neglecting vertical wind effects strongly depends by the variable considered (i.e. Rain , LWC or D_0 etc…) .*
- ○ *Retrievals of Rain and LWC are the most sensible to vertical winds*

8. REFERENCES

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